

MITIGATING THE RISK OF A NEW WORKFORCE BY REDUCING REWORK AND RIGHTSIZING ON HAND INVENTORY

By

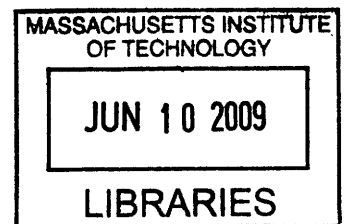
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Submitted to the MIT Sloan School of Management and the Engineering Systems Division in Partial
Fulfillment of the Requirements for the Degrees of

**Master of Business Administration
AND
Master of Science in Engineering Systems**

In conjunction with the Leaders for Manufacturing Program at the
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ABSTRACT

Dramatically increasing the hourly workforce at a rapid pace to support accelerated product demand in an aircraft manufacturing facility in a short amount of time resulted in: (1) increased rework, and (2) increased part damage during assembly.

The majority of rework results from simple workmanship mistakes from the new workforce. The approach used in this thesis to combat the increase in rework involves the design and implementation of a feedback loop on the shop floor of a leading aircraft manufacturer. The loop consists of providing each worker with a list of their discrepant work from the day before and the opportunity for them to perform their own rework. The thesis shows that the percent of discrepancies reworked by the original mechanic increases from 27% to 41%. Paired data is analyzed to show (on average) a 20% decrease in rework when the feedback loop is utilized. Included is qualitative advice on implementing change on the shop floor.

During final testing, damaged parts (typically as a result of out of sequence work or workmanship mistakes) are discovered and require immediate replacement. Frequently, there are no replacement parts available at the test site, since the original part was installed by a subcontractor. To meet the immediate replacement need, test personnel remove an already installed part from an aircraft upstream in final assembly at the same location. The thesis includes a case study to demonstrate a binomial demand model to estimate the amount of on hand safety stock required to prevent the unnecessary labor from the redundant part removal and replacement from upstream aircraft. The case study estimates demand based on the probability of finding a damaged part, the takt time of the particular model, the leadtime and delivery quantity of replacement parts. A cost tradeoff is calculated to justify the additional capital investment in inventory.

The thesis closes with a leadership case study on whom and how to handoff a shop floor Tip of the Day system for the new workforce to ensure its continued success.

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I wish to acknowledge the Leaders for Manufacturing Program for its support of this work.

I wish to express sincere appreciation to USAircraft, particularly to the entire final assembly operations team (everyone from the general manager to the newest mechanic) that work tirelessly to produce aircraft to help the United States of America win the global war on terror and protect the freedom that have enabled us to continue to learn and grow our families safely and securely.

I am indebted to the support and advice of both of my advisors, Professor Graves and Professor Nightingale. They have relentlessly pushed me to get out of my comfort zone and figure out what is really going on, and have provided critical insights and ideas to keep me moving forward. I am in debt for their counsel in turning my internship experience into a knowledge sharing thesis.

I would like to thank my classmates in MIT's Leaders for Manufacturing program, their support and teachings have been invaluable and I don't think I'll ever work with a more capable, intelligent, and caring group of peers. I encourage them to stay in touch, and let them know if they ever need anything to just call, I will be happy to listen, share, and learn.

As with all of my educational endeavors, none of them would have been possible without the loving support of my family, especially my father and mother.

Most importantly, my thanks, appreciation, respect, and unyielding love go to my wife. Without her support, love, daily guidance, encouragement and advice I'd be lost. She deserves extra appreciation for not only supporting me financially and emotionally during my education, but also for bringing our daughter Annabel into the world during my internship.

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DISGUISED INFORMATION

This thesis was prepared in close co-operation with a leading aircraft manufacturing company in the United States. To protect potentially sensitive information and to ensure competitors do not gain competitive advantage from the information contained herein, the company's name will be disguised as USAircraft. Per USAircraft's request, potentially sensitive or specific identifying information is also disguised. Data disguised will be noted with an asterisk (*) where possible. Most notably, the scale has been removed from a number of plots. Also, several sources have been disguised to prevent revealing USAircraft.

Chapter 1 INTRODUCTION

This thesis addresses two common effects of a new workforce: an increase in rework and an increase in rejected/damaged parts. The implementation and results of a reworkable discrepancy feedback system on the shop floor of a leading American aircraft manufacturing company (USAircraft) is described and the effect on rework analyzed. Included is a case study detailing how to properly size inventory buffers to account for unplanned part rejections. One additional case study is included to address the issues of empowering others to continue a system once the change leader moves on.

USAIRCRAFT BACKGROUND¹

USAircraft was started early in the 20th century by some of the original innovators of manned flight. USAircraft is based in the United States and builds a variety of aircraft. The largest customer is the United States military, but USAircraft sells to various commercial air carriers, private companies, VIP's, as well as foreign militaries and governments. The company has plants throughout the United States, as well as some in Europe and China. USAircraft produces a variety of models to meet the needs of its various customers. USAircraft is organized into various business units organized around sections of the aircraft as well as final assembly, supply chain, facilities and the program office. Each business unit serves as their own profit and loss center. USAircraft is renowned for their safety and reliability, as well as an extensive parts and support network for their customers.

USAircraft originally built the entire aircraft in their home plant (except the engines), but as orders increased they began to slowly outsource various parts of the airframe and other

¹ (USAircraft)

subassemblies to subcontractors throughout the US and the world. USAircraft's labor force in several US plants is unionized, but their subcontractors typically are not.

With the war effort in Iraq and Afghanistan, USAircraft has seen a substantial increase in sales and backlog, and has both outsourced more work and increased the workforce in final assembly to keep up with demand. Over 80% of the current hourly workforce was hired in the last two years. In Figure 1 we show the increase in revenue and backlog over the last few years.

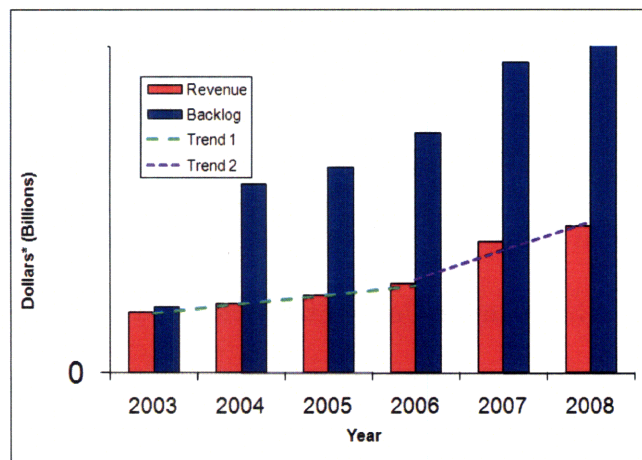


Figure 1: USAircraft Revenues and Backlog²

The final assembly workforce includes various types of assemblers (for simplicity we refer to hereafter as “mechanics”), team leaders, and inspectors. The final assembly of an aircraft is done in a fixed number of positions on the shop floor. Depending on the model of aircraft there are between 5 and 12 assembly positions. The aircraft “rolls” from position to position every 2* days. The work in each position is broken into 10*-30* individual assembly operations (adding a component, routing a cable, rigging a flight control, etc.). Each assembly position is large enough for 1 aircraft and the associated work stands, tools, and parts. Typically 1 or 2 mechanics work on a single operation at a time. There is an IT system the mechanics log into to obtain work instructions and drawings, as well as check off various steps as they are completed. After an operation is

² (USAircraft, 2003-2008)

complete, the mechanic flags the operation as ready for inspection in the IT system and it goes into the inspection queue for that position. The inspector assigned to that position will inspect the operation to ensure it is done according to the print and workmanship standards. If there are any problems the inspector will write a discrepancy in the IT system for each individual problem and these will go into the queue for the mechanics to rework. The supervisor will assign each discrepancy to a mechanic, and the rework will be performed and put back into the queue for re-inspection.

As the aircraft moves down the line, eventually all the wiring is complete and the power and hydraulic systems are energized. Operational checks are begun and additional rework is discovered. In the final position a series of final inspections are performed to ensure all work is complete and to print. This is the final chance for rework to be discovered and corrected in final assembly. Once all rework is complete and re-inspected, the aircraft rolls to the paint shop, and into the hangar for ground runs and flight tests.

INTERNSHIP

This thesis is based on work done at USAircraft over a short period of six and a half months by the author working as a Leaders for Manufacturing intern within USAircraft. The internship was focused on the final assembly business unit. Final assembly is responsible for putting together the major components, and testing the aircraft through in factory tests, ground runs, and flight tests. The thesis is based primarily on work done at the main plant on three variants of an aircraft sold to the US military.

THESIS STRUCTURE

The next three chapters detail the rework problem, approach, and results. Chapter 5 includes the author's reflections on leading change on the shop floor. Chapter 6 is a case study dealing with a technique to properly size on hand inventory to account for rejected parts found

during ground runs and flight tests. Chapter 7 is a case study meant for class discussion on how to effectively hand off work.

Chapter 2 PROBLEM DESCRIPTION

This chapter goes into more detail on the production process, describes a number of contributing factors to the increase in discrepancies, and lays out four objectives for any countermeasure to mitigate the increase.

Over 80% of the hourly workforce in final assembly has less than 2 years experience with USAircraft. With the influx of new employees and increased demand, the number of reworkable discrepancies³ has increased by 20% to 30% on an aircraft by aircraft basis over a year ago. The problem addressed in this thesis is to find a root cause and to implement countermeasures to reduce the discrepancies.

PRODUCTION PROCESS

In order to understand the factors contributing to the increase in discrepancies, it is necessary to go into more detail on the production process. Chapter 1 provided a brief explanation on how work is broken up into positions and each position has a set number of operations. Figure 2 below shows the basic flow of how work on one operation progresses.

³ A *reworkable discrepancy* is something inspection found not to print that can be easily repaired by the installer. Each discrepancy requires rework, increasing flow time, as well as opportunities for a quality escape. Typical reworkable discrepancies include: stripped screw head, incorrect fastener length, touchup paint required, incorrect label, interference between wire harness and hydraulic lines. A *quality escape* is work found not to print that is not repaired by USAircraft personnel and either found in the field or by a government inspector. A *non-reworkable discrepancy* is work not to print that the mechanic cannot rework to the drawing on their own. The rework may require a special shim or repair operation, or the replacement of an entire part.

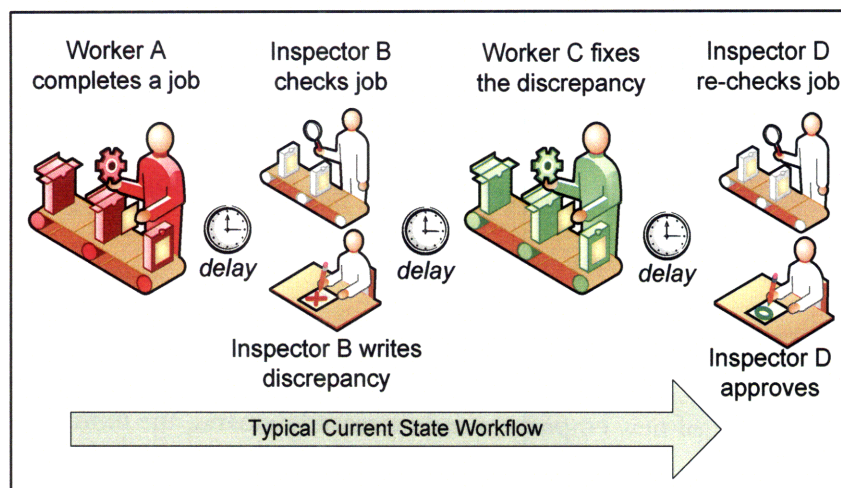


Figure 2: Typical Current State Workflow

When the aircraft rolls from position to position, during the next shift the materials handler delivers the parts required for the next set of operations. In the IT system, the operations are flagged as “workable” and the supervisor or team leader for that position assigns the work to a mechanic on their team. Using the work instructions and drawings available on her tool box terminal, the mechanic performs the required operation, using parts and tools as needed. If a part is not available or a mechanic does not have the necessary skills, they alert their supervisor or team leader and the work operation may stay open and be carried forward to the next position until the situation can be resolved. Some operations cross shifts and multiple mechanics will work on the same operation; other operations might be worked by the same mechanic in the same day or across multiple days. Electronically, the mechanic “stamps” off the operation as it is complete, and the operation is flagged for “inspection” in the IT system.

The inspector assigned to the aircraft monitors the electronic inspection queue for operations to inspect. Typically the work is inspected by an inspector on a different shift than the mechanic. The inspector uses a clipboard, flashlight, mirror, work instructions, and any applicable drawings to check the mechanic’s work. If discrepant work is found (not in accordance with the drawing or applicable USAircraft quality standard), the inspector records the operation number,

location on the aircraft, brief description, and applicable drawing or part number. Back at their terminal the inspector creates one electronic discrepancy for each issue found. These discrepancies go immediately into the “workable” status for the particular aircraft.

A supervisor or team leader (typically in a downstream position and different shift) prints out a list of all workable discrepancies on an aircraft and assigns them to a mechanic or team of mechanics. These mechanics review the inspector’s notes, find the issue, rework as needed, and then mark the discrepancy as “inspection” electronically.

The inspector assigned to the aircraft (again typically in a downstream position and on a different shift) monitors the inspection queue. They review the original inspector’s notes, find the issue, check it, and if it passes they mark the electronic discrepancy as “closed” electronically. If the issue remains, or an adjacent or additional issue is found, they re-open the discrepancy or write a new one and mark it “workable” electronically and the process continues.

Eventually in the final position, all operations and discrepancies are closed, and the aircraft “rolls” to paint and into the hangar for test flights.

FACTORS CONTRIBUTING TO INCREASED REWORKABLE DISCREPANCIES

The six factors contributing to the increase in rework can be attributed to two main causes: increase in demand and schedule pressure.

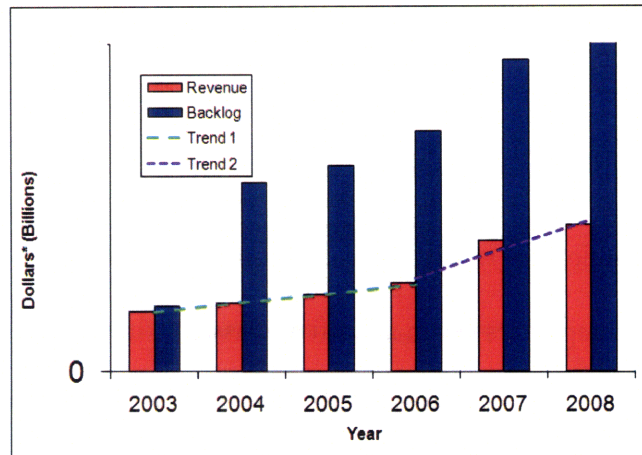


Figure 1: USAircraft Revenues and Backlog⁴

As shown above in Figure 1 (repeated from page 10), there is a marked increase in demand in 2004 and 2007, and a much smaller increase in total production (as measured by revenues). The increase in demand can be attributed to the increase in the US military activities in Iraq and Afghanistan. In order for USAircraft to capitalize on this increase in demand, they must increase production capacity. In addition to the profit incentives, the US government (in an effort to help those in harm's way) has put tremendous schedule pressure on USAircraft to produce more aircraft as soon as possible.

Through interviews and direct observations, the increase in demand and schedule pressure leads to six contributing factors: new workforce, reduced training, overtime incentives, inspection practices, more carry forward work and handoffs and increased outsourcing.

NEW WORKFORCE

The assembly of the aircraft is done largely through the use of highly skilled touch labor. In order to produce more aircraft in the same amount of time, USAircraft dramatically increased hiring. Over 80% of the hourly workforce was hired in the last 2 years. To become proficient at assembling aircraft requires a high degree of skill and hours of practice or specific job experience. Even

⁴ (USAircraft, 2003-2008)

experienced mechanics from outside USAircraft can take up to 5 years to equal the productivity of USAircraft's experienced workforce (20%). The new workforce is much more prone to make mistakes and damage parts than the experienced workforce. These mistakes lead to increased discrepancies and damaged parts.

REDUCED TRAINING

In order to give the new workforce as much on the job training as possible, the in classroom and practice shop training was reduced. In interviews with mechanics asking about why there was an increase in discrepancies, 90% mentioned the training they received was insufficient and frequently they had to learn the hard way by making mistakes on the job. The ratio of four inexperienced to one experienced worker is well over the ideal one to one ratio. The one to one ratio allows the experienced worker to closely supervise and train one inexperienced worker at a time. Four to one is just too much work for one experienced worker to mentor. The reduced training is one factor in the increase in rework.

OVERTIME INCENTIVES

USAircraft's hourly workforce is unionized, and the union contract includes generous overtime provisions. There is a clear pay incentive for mechanics to work overtime. This worker incentive for more overtime is a very powerful force. The mechanic's view is the more rework, the more overtime, the more pay they will receive. This reinforcing loop leads to more rework.

INSPECTION PRACTICES

In multiple interviews with mechanics, inspectors, supervisors, and line managers there is a perception that if an inspector does not find any discrepancies on a job, she is not looking hard enough. Multiple interviewees recounted stories of inspectors that will look at a job until they find at least a few discrepancies. The nature of the 100% visual inspection of multiple assembly operations done in the same small, dimly lit space on an aircraft, lead to a large gray area of whether

a particular job is acceptable or not. This inspection incentive to always find something, and the subjective gray area in a number of inspection standards lead to more discrepancies.

In addition, the new workforce is not just limited to mechanics. Quite a few of the inspectors are also new to Sikorsky. To ensure the safety of those who will fly and ride in the aircraft, the new inspectors are taught: when in doubt, write a discrepancy. The idea is to err on the side of caution and have the mechanic take another look at any questionable issue. This practice coupled with the new inspectors leads to an increase in discrepancies written.

MORE CARRY FORWARD WORK AND HANDOFFS

Each position in the final assembly line has a fixed set of assembly operations assigned. For example in one position, the tail is attached, main wiring harnesses rough routed, and the cockpit prepped. In the next position the main wiring harnesses are tied up, half of the floor panels installed, and the tail wired. The industrial engineering team in cooperation with the team leaders and supervisors carefully laid out the work by position to ensure each position's work can be done without removing a previous position's work, and mechanics in the same position have enough room to work. With the increase in schedule pressure, frequently work is carried forward from position to position. This causes mechanics to work out of position, work on operations out of order, and handoff jobs across shifts and positions. This definitely leads to more discrepancies as mechanics bump into each other, have to work around partially complete jobs, and have to pick up another mechanic's job they may not trust.

INCREASED OUTSOURCING

Finally, in order to meet cost targets and the increase in production, USAircraft has steadily increased the number of parts that are outsourced. In the distant past, 90% of the parts on an aircraft were made in the same building as the final assembly. This made it very easy for a final assembly mechanic to walk a part back to the shop where it was first made and quickly work with

the folks there to solve any sort of discrepant work. With the outsourcing, the communication and problem solving takes more effort and time, and is frequently neglected due to schedule pressure. This reduction in direct communication and problem solving leads to more rework of vendor parts by final assembly mechanics.

GOAL AND OBJECTIVES OF THE COUNTERMEASURES

The overall goal of the countermeasures is simple: reduce and eliminate rework wherever possible.

The specific objectives are threefold: reduce labor hours spent on rework, increase the likelihood of discrepant-free work, and improve workmanship quality. The primary objective is to reduce labor hours spent on rework. USAircraft has conducted multiple studies and has a well defined estimate of how much labor each discrepancy takes to rework and re-inspect (withheld). The exact number of discrepancies is withheld, but the potential annual cost savings in eliminating these discrepancies is in the tens of millions of dollars. The secondary objective is to increase the likelihood of a mechanic performing discrepant-free work, thus eliminating the need for rework or even inspection. The tertiary objective with the new workforce is to improve workmanship quality across the shop floor. The most important objective is to implement sustainable countermeasures that will continue to reduce the number of discrepancies for years to come.

Chapter 3 APPROACH

There is a wide variety and vast amounts of literature describing different approaches to reducing rework and improving quality. Of particular note are the concepts described in *Lean Thinking* by Womack and Jones, and exemplified by the Toyota Production System. *Lean Thinking* describes key concepts like *jidoka*, autonomation, and *poka-yoke* or mistake proofing⁵. The first step in implementing any of these concepts is to ensure any mistake (or discrepancy) is visible to everyone immediately, especially the shop floor worker and to stop the process so further mistakes are not made. This is a basic principle in the approach to reducing rework.

USAircraft has a companywide continuous improvement team and training program. The training website details three levels of mistake proofing:

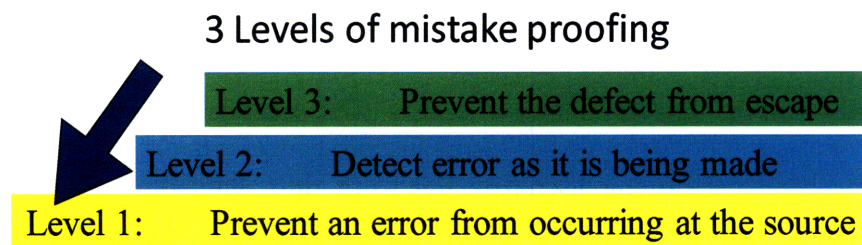


Figure 3: Three Levels of Mistake Proofing

In the author's opinion, USAircraft is excellent at level 3, preventing any escapes⁶. The approach taken in this thesis is to work towards the other two levels: detect errors as they are made, and prevent errors from occurring at the source.

USAircraft conducted a kaizen intent on reducing the number of reworkable discrepancies with a cross functional team from final assembly (inspectors, engineers, mechanics, supervisors, managers, the author, continuous improvement experts and an outside lean sensei). The kaizen

⁵ (Womack, et al., 2003 pp. 347-351)

⁶ An *escape* is work found not to print that is not repaired by USAircraft personnel and either found in the field or by a government inspector.

team came up with a threefold approach to reduce rework: institutionalize a daily tip to address the more common discrepancies, implement a comprehensive training program, and create a better feedback loop between inspectors and mechanics.

TIP OF THE DAY

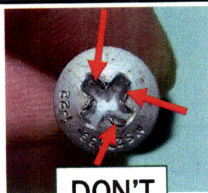
TIP OF THE DAY

Stripped fastener heads fall into the category of obvious damage, and are frequently written up as an reworkable discrepancies.

How can I prevent my fastener heads from stripping?

A few common sense tips worth going over with the new folks:

1. Ensure you are working in **good lighting**. Use a drop light, flashlight, even a headlamp.
2. **Check your driver tip**. If it is damaged, worn, stripped this not only introduces FOD, but also increases the odds of a stripped fastener. New driver tips are available at the tool crib.
3. Use the **right tool for the job**. #2 works for the average size screw, use a #1 on a smaller screw. If you are unsure ask your peer, lead, or supervisor for a quick lesson.
4. **Check the length** of the screw before driving.
5. Ensure **driver is square on the screw head**. Driving at an angle is almost guaranteed to strip the fastener head.
6. **Take your time**, and **drive fastener slowly**, this isn't NASCAR, it is more important to do it right the first time, than do it quickly and have to do it again.
7. If possible, use a **hand screw driver** for those last few turns.
8. Once complete, take 5 seconds and **just look at the fastener head**. It is much easier/faster to replace a stripped head now, than pass it down the line to the next installer to fix, or even on to the customer.



DON'T



DON'T

TIP OF THE DAY

Do's & Don'ts

Q: I know I've got my minimum 2 pitches to break safety, but How many threads are too many?

A: As long as:

Fastener size is to the print (or allowable substitute, typically ± 2 sizes)

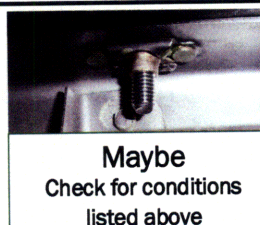
No clearances are violated (doesn't hit anything)

Fastener does not bottom out in the nut

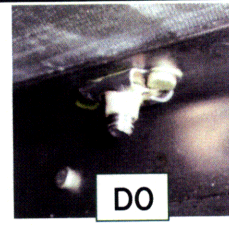
All load/shear is carried by the non-threaded portion

Then your installation is good to go.

*USAircraft quality standard proprietary
information removed*



Maybe
Check for conditions
listed above



DO

Figure 4: Tip of the Day Examples

Two examples are shown above in Figure 4. This approach is a form of on-the-job training, and consists of a simple daily email sent to each supervisor. At the beginning of the shift, the supervisor would review the tip with their team of mechanics and inspectors. Tips were generated by the hourly workforce and quality engineers, formatted by the continuous improvement team, and reviewed by the mechanic's school instructors before distribution. The tips consisted of simple easy to follow advice for the mechanics. They included topics like: how to prevent a screw from stripping, safety tips on how to place the work stands, clarifications of workmanship standards, and relevant facts and stories stressing the importance of removing foreign objects from the aircraft.

Talking and distributing the Tip of the Day were left up to the shop floor supervisor's discretion, as not all tips would apply to all personnel. Due to the sporadic distribution of the tips, the results of this approach are not quantitatively measureable and are not included in the thesis.

COMPREHENSIVE TRAINING

With the influx of new employees, and the complexity of assembly aircraft, the mechanics school was overwhelmed and quite a few new mechanics were trained on the job. During widespread interviews with shop floor mechanics and inspectors, 90% requested more training tailored to their specific operations on the aircraft (above and beyond the standard training). This task was delegated and undertaken by USAircraft's mechanics training school, and the results are not included in this thesis because the improvements were not complete at the conclusion of the author's internship.

FEEDBACK LOOP

Based on interviews, observations, and discussion among the kaizen team the following current state workflow (Figure 2 repeated from page 14) was created:

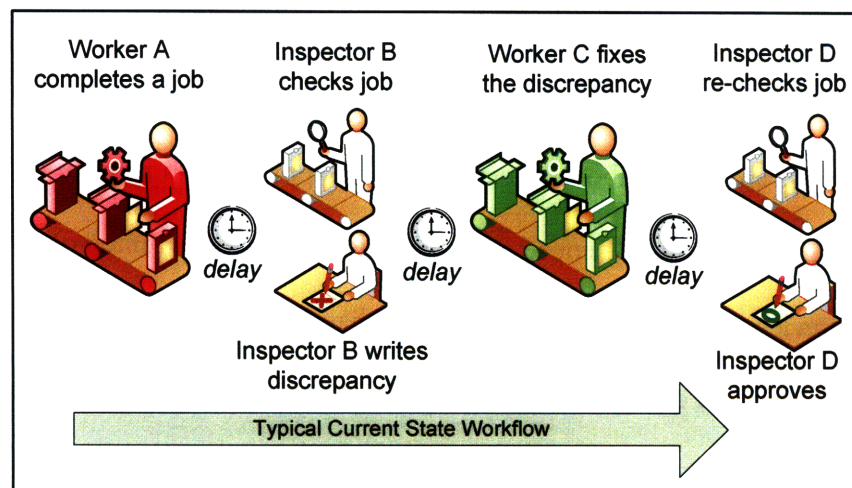


Figure 2: Typical Current State Workflow

Mechanic A completes an operation, inspector B then checks the job and if there is any work not to print, they write an electronic discrepancy. Due to the schedule pressure and fixed “roll” rate, the vast majority of discrepancies are reworked by a different mechanic, typically on a

different shift and working in a downstream position. The original mechanics rarely see their own discrepancies, or rework them. The kaizen team proposed an improved future state with direct feedback to the original mechanic:

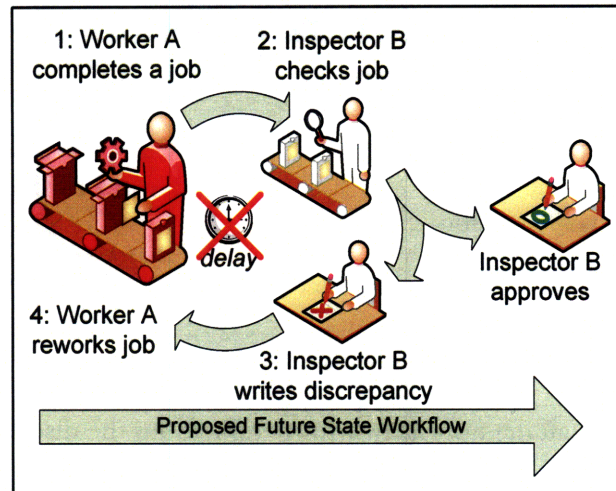


Figure 5: Future State Workflow

In the future state, the same mechanic and inspector team work the job and any discrepancies until they are completed. The hypothesis is: ***a mechanic that is aware of his or her discrepancies and is responsible for reworking them will be less likely to create future discrepancies and therefore reduce rework.*** By working their own discrepancies, mechanics would have more ownership and accountability in their work, and in addition create more opportunities for learning. Their mistakes will be much more visible, which is always the first step in soliciting their help to reduce them in the future.

The system implemented consisted of an automated IT report that would retrieve all of the discrepancies that had yet to be worked from the online database. These would be linked to the mechanics that did the operations originally. A report was generated for each mechanic with the mechanic's name, their supervisor, and a list of the workable discrepancies from their jobs. These reports were emailed to the supervisors and distributed at the beginning of the shift to the

mechanics with the instructions to rework these discrepancies first, before continuing on to their next operation.

Installer: Mechanic XYZ										Supervisor: John DoeXYZ	
INSTALLER REPORT										Model: ABC	
Inspector	Eff	Src Dept	Part No	Part Title	Aircraft Loc Code	Station Line	Water Line	Butt Line	Remarks	ORDER #	
Inspector A	069	3234	12345-ABCDEF-1	PART INSTALL	Top Deck	325	283	10L	THE -054 ROD -101 BOLT HEAD HAS 2 STRIPPED POINTS.	8900239124- -A000 003	
Inspector B	071	3234	12345-ABCDEF-1	PART INSTALL	Top Deck	317	275	5 L	Cotter pin cut short on bolt that attaches -053 (Lateral) rod to servo.	8900243487- -A000 001	
Inspector B	071	3234	12345-ABCDEF-1	PART INSTALL	Top Deck	317	275	5L	MS21244-12 Nut causing disbonding of UP/FWD ident on -053 rod	8900243487- -A000 003	
Inspector B	072	3234	12345-ABCDEF-1	PART INSTALL	Top Deck	N/A	N/A	N/A	Support Assy (12345-ABCDEF-1) is missing ID decal. Unable to collect serial number with bar code reader.	8900245650- -A000 018	

Figure 6: Sample Discrepancy Report*

The report contained all the necessary information about the discrepancy, including: which aircraft (Eff), the operation (Part No and Part Title), the location on the aircraft (Aircraft Loc Code, Station, Water and Butt Lines), the description (Remarks), and the discrepancy identifier number (Order #), as well as the name of the inspector that wrote the discrepancy.

This system seems foolproof, but the kaizen team foresaw a number of possible pitfalls. The attitude on the shop floor was that fixing discrepancies was the job of the newest/lowest seniority mechanic on the team, so the idea of getting 20-year experienced mechanics to fix their own mistakes would be a challenge for the supervisors. Despite the fact the shop-floor IT system had been around for years, quite a few mechanics would still rely on their team leader to mark their jobs as complete. This would put the team leader's name on the discrepancy report and the discrepancies wouldn't make it to the original mechanic. The prevailing attitude of the mechanics was that quite a few of the discrepancies were frivolous or incorrect, and they would be upset to see their name associated with phantom mistakes. There was the issue of whose name to assign to a discrepancy written against an operation that five mechanics worked on across 3 different shifts; if the system picked the wrong mechanic, this mechanic would surely become enraged. Finally, due to

the intense schedule pressure, the team was unsure if a supervisor could be convinced to have his most experienced mechanics working discrepancies, when they could be working on critical path operations, and leaving the discrepancy work to those mechanics that were not trained on the critical path operations.

To aid management in encouraging adoption and tracking results, a set of daily metrics was created (shown below in Figure 7).

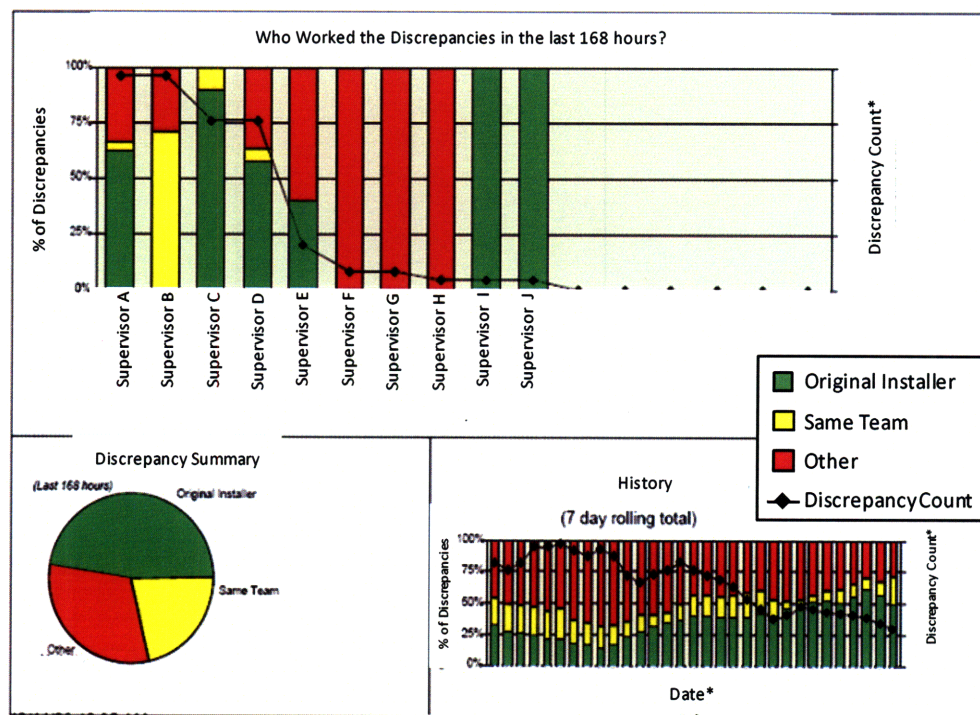


Figure 7: Daily Metrics

The top box shows by supervisor what percent of the discrepancies created by her direct reports in the last week were worked by the original mechanic (green), a mechanic on the same team (yellow), or someone else (red). The total discrepancy count by supervisor is also shown in a black diamond. The lower left shows a pie chart summary of all the discrepancies worked in the last week for the entire line. The lower right chart shows the history for the last 30 days of how many discrepancies were worked by whom. This aided in tracking trends. In this particular example the

number of discrepancies is trending down, while the percent of discrepancies worked by the original installer is trending up.

The adoption and effectiveness of this system are discussed in the next chapter.

Chapter 4 RESULTS

USAircraft's final assembly shop floor is a complex system with many factors that influence the number of discrepancies. USAircraft routinely measures the number of discrepancies per aircraft, operation, mechanic, etc. We expect that as mechanics work more of their own discrepancies, their discrepancy count will decrease (along with the total number of discrepancies per aircraft). The tough part is determining which factors cause the discrepancy count to increase or decrease. The concept of the feedback loop is simple, but measuring clear results with so many other factors is more difficult. The shop floor is not a laboratory environment where all but one factor can be held constant. Other factors include: experience level of the mechanic, number of times the mechanic has done the same operation on multiple aircraft, how many mechanics work on the same operation at a time, schedule pressure, lag time to inspection, quality of incoming materials, and the delays from inspection to rework.

This chapter provides background on the data collected. By analyzing this data, one can see trends that more and more mechanics are working their own discrepancies (the system was implemented and used correctly, although slowly adopted) as time goes by. Two sets of data are plotted to show

As more discrepancies are worked by the original mechanic, less discrepant work is created (the hypothesis is correct, and the system reduces rework). Finally, a correlation is suggested between total discrepancy counts by aircraft and the % of discrepancies worked by the original mechanic on the previous aircraft.

DATA SET

USAircraft is very good at collecting all sorts of data. The shop floor IT system is available right on each mechanic's toolbox and logs the time and mechanic's ID for every operation that is complete. The system does the same thing for each inspection. The data analyzed in this chapter

includes the operation identifier, mechanics’ IDs that worked the operation, the aircraft, the number of discrepancies, time stamps for operation complete, and the mechanic ID that reworked each discrepancy. The data spans 6 months and includes over 40 different aircraft of the same model.

The thesis will use the number of discrepancies found on each operation as a measure of the amount of rework. This is not an exact correlation to the amount of hours spent on rework, but is the best available. USAircraft has conducted a number of studies and they have established an average amount of rework labor per discrepancy (exact value withheld). In reviewing the time clock and discrepancy data for one day on one aircraft, the author found the discrepancy counts to have finer detail and better consistency than the time clock data.

WAS THE FEEDBACK SYSTEM USED?

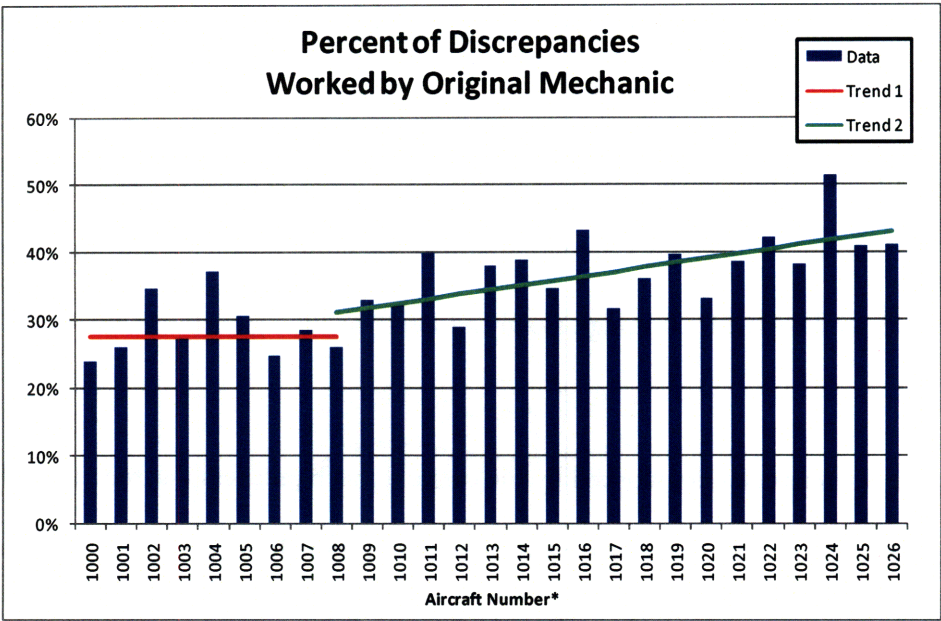


Figure 8: Discrepancies Worked by Original Mechanic by Aircraft

The system was slowly implemented starting with aircraft number 1009*. Figure 8 above shows the percent of the total discrepancies found on an aircraft that were reworked by one of the mechanics that performed the original operation. Before the system was implemented on average about 27% of the discrepancies were worked by the original mechanic. Looking at a least squares linear fit after implementation (“Trend 2” line in Figure 8), we observe that the percentage rose to

~41% over 18 aircraft at about 0.78% per aircraft. There is some variation that can be attributed to some supervisors not regularly using the system, as well as some glitches in the IT report generating system. On the shop floor, there is huge schedule pressure to complete operations and move aircraft forward. Falling behind schedule and taking longer than expected were unacceptable and managers came down hard on supervisors that did. There is no doubt in the short run, having each mechanic work his or her own discrepancies (typically on an aircraft that has rolled to a different position) takes more time, than assigning all the discrepancies to one or two rookie mechanics. Overall, the increasing trend is encouraging and suggests that the system was used as intended, but did not achieve 100% adoption.

In interviews with mechanics and supervisors, about 20-40% of the discrepancies could not be worked by the original mechanic due to a variety of reasons including: part shortages, special skill required, and/or absenteeism. At one point, there was a gap in the supply chain of labels for the various connectors and cables. In order to minimize the delay due to the stock out, mechanics would mark an operation as complete, even though the label was never installed. Inspection would check the job, and create a discrepancy that the label was missing. These discrepancies would sit open until the labels were in stock, and typically one mechanic would install all the labels (leading to a large percentage of discrepancies worked by a different mechanic).

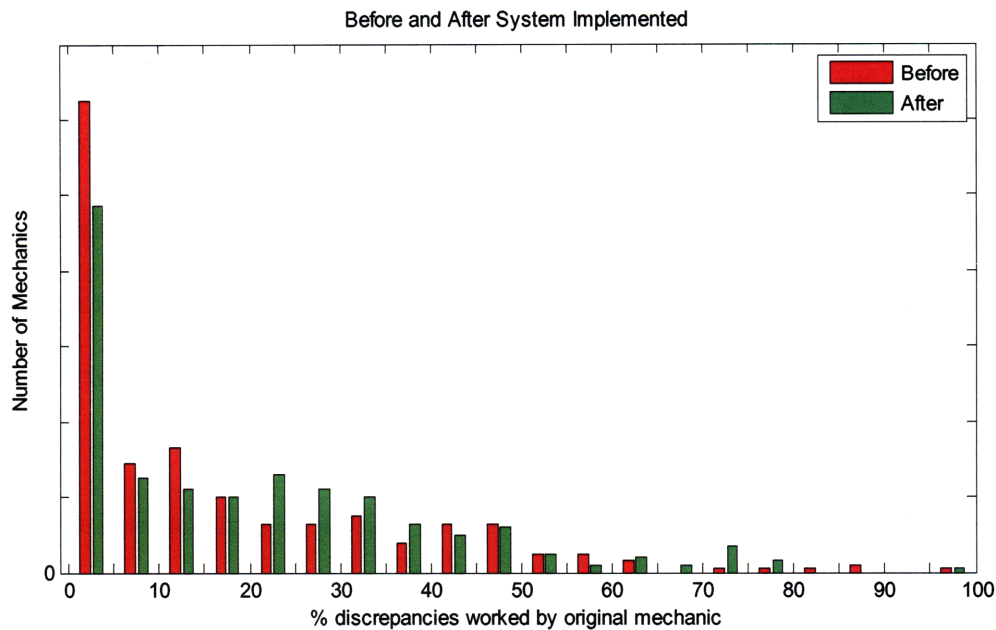


Figure 9: Histogram of Discrepancies Worked by Original Mechanic

Figure 9 above divides the data into 2 sets (before the feedback system was implemented and after) and shows the number of mechanics working various percents of discrepancies on their own operations. For each set, the number of discrepancies actually worked by the original mechanic was tabulated and divided by the total number of discrepancies assigned to that mechanic. Note the histogram shifts to the right (more discrepancies worked by original mechanic) after implementation. Notably, there are 21% fewer mechanics working less than 10% of their discrepancies after implementation than before. That's 21% more mechanics that are seeing at least some of their discrepant work in a timely manner (more visible), and are beginning to help the team come up with mistake proofing ideas to prevent discrepant work in the future.

The data shows as the system was adopted, more mechanics are working discrepancies on their operations. The data also shows there is substantial room for additional adoption. The question remains: was the amount of rework reduced due to the increase in feedback?

OVERALL DATA

Figure 10 below shows all of the data set at a glance, and includes a point for each unique mechanic. For example: Bob is a mechanic working on this line. The X axis is simply the total number of discrepancies that Bob reworked himself from all his own operations divided by the total number of discrepancies the inspector found on all of his operations. The Y axis is a scaled number* that represents the average number of discrepancies the inspector found on each of Bob's operations. For example, if Bob completed 2 operations on 5 different aircraft, and the inspection team discovered 10, 9, 8, 7, 6, 5, 4, 3, 2, 1 discrepancies on each operation, Bob would have an average of 5.5 discrepancies per operation.

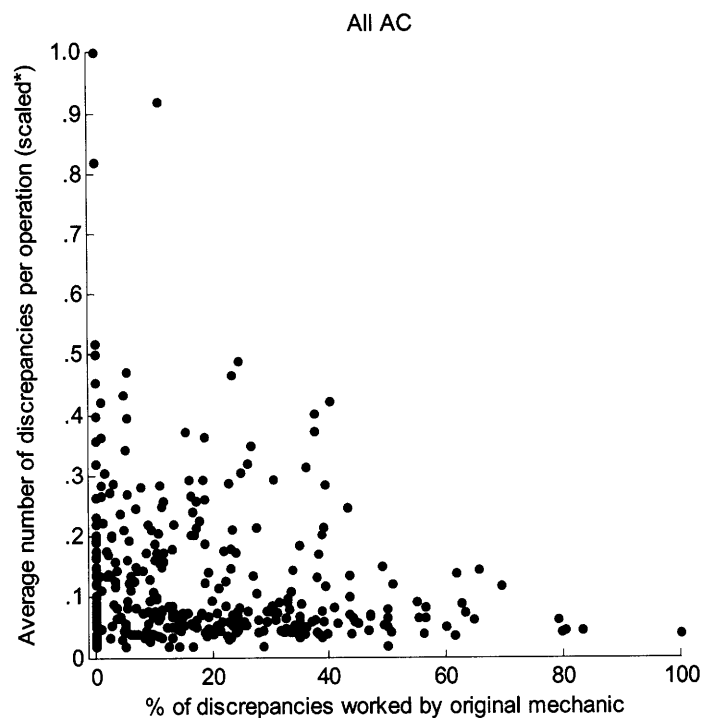


Figure 10: Average discrepancies versus % worked by original mechanic

Figure 10 above shows that the range of average discrepancies is greatly reduced when the original mechanic works 50% or more of their own discrepancies. For 50% or more discrepancies worked by original mechanic, the range is between 0 and 0.17 (scaled*) average number of discrepancies per operation. While, for 50% or fewer discrepancies worked by original mechanic,

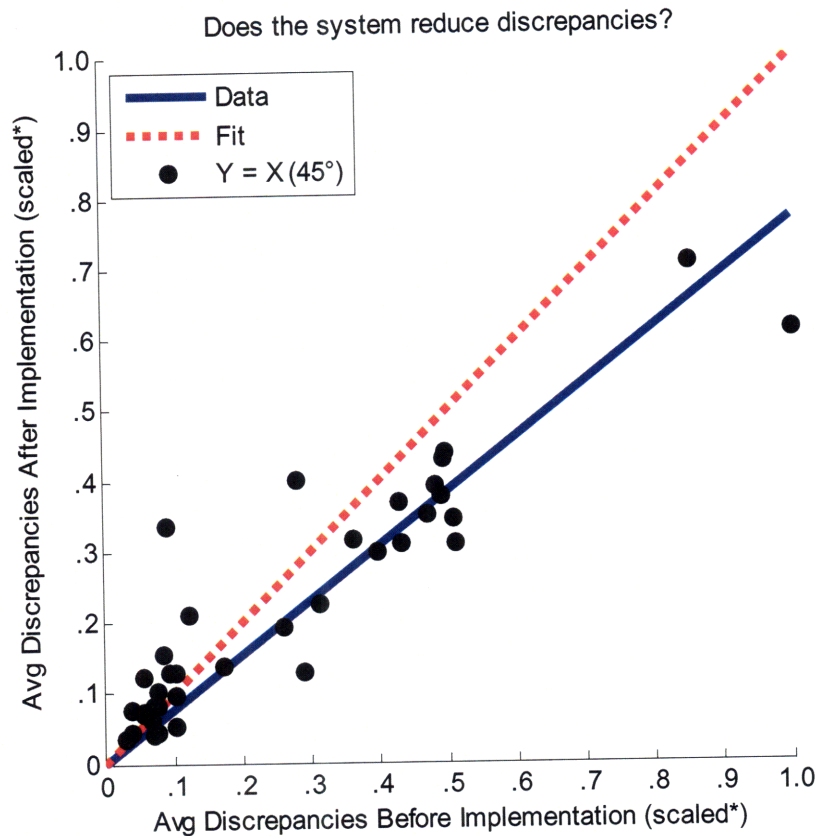
the range is from 0 to 1.0 (scaled*) average number of discrepancies per operation. This is consistent with the hypothesis.

PAIRED DATA

To eliminate as many of the other factors mentioned in the beginning of this chapter, a paired data set is analyzed. The pairing consists of the same mechanic working the same operation before the system is implemented, compared to the same mechanic working the same operation (although on a different aircraft) after the system has been implemented. As there was an increase in employees during the study as well as reassignments from line to line, there are surprisingly few paired sets of data. The data is limited to:

- Mechanics that performed the same operation on at least 2 aircraft before and after system implementation.
- Operations with at most 20% of discrepancies worked by the original mechanic before the system was introduced (little to no feedback before).
- Operations with more than 50% of discrepancies worked by the original mechanic after the system was introduced (quite a bit of feedback).

The system was rolled out to each shift and supervisor at different times, and these times were not recorded. As an approximation, for each mechanic we considered the first operation when they worked over 65% of their own discrepancies to be when the system was implemented on their team. These limitations ensure there is a reasonable sample of mechanics who were not using the system before, and definitely are after. The data set with these limits includes 37 unique mechanic/operation combinations. For example if Bob works on the panel installation and also the window, there will be 2 points: Bob/panel and Bob/window. The axes are simply the average number of discrepancies the inspector found on Bob's panel operations before (X-axis) and after (Y-axis) the feedback system was implemented. Both are divided by the same scale factor to protect confidential information. If rework is not reduced, one would expect the data to fall along a 45°, $Y = X$ line shown in dashed red.



The blue line shows a linear fit to the data with a slope of 0.771 (with a 95% confidence interval between 0.88 and 0.66). Removing the two outliers (over 0.7 scaled average discrepancies before implementation) results in a slope of 0.811 (with a 95% confidence interval between 0.948 and 0.674). Since the slope 1 is not included in the confidence interval, rework is definitely reduced by the feedback system. In fact the slope would suggest a reduction in discrepancies of over 20% from before to after.⁷

An additional test to determine if this is statistically significant is a dependent/paired t test. The null hypothesis that there is no difference between the average number of discrepancies per operation before and after is rejected with less than 6% significance (the 90% confidence interval for

⁷ (Larose, 2006 p. 60)

the mean is positive from 0.0047 to 0.0636) and we can conclude the difference between before and after probably represents a real difference.⁸

LEARNING CONTRIBUTION

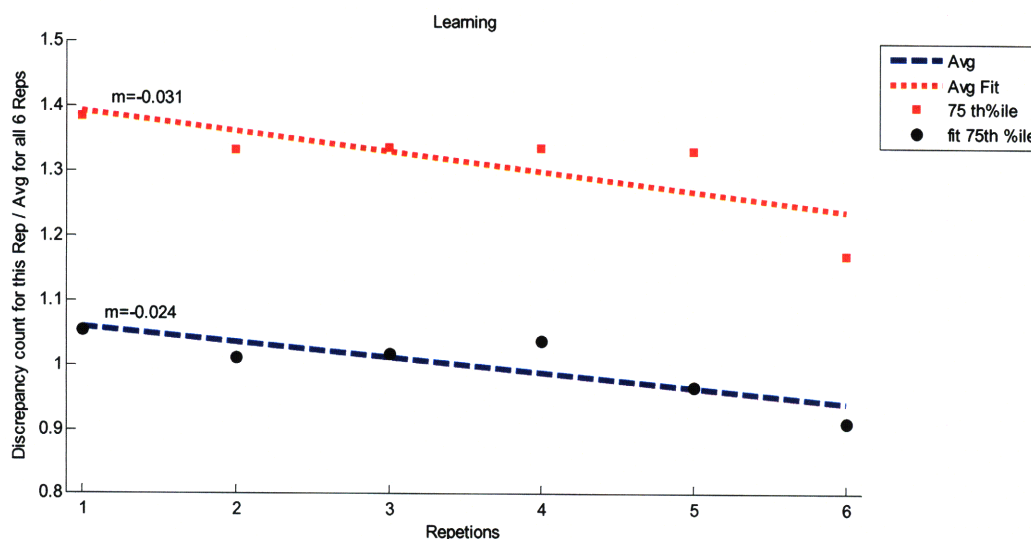


Figure 12: Learning

Since the mechanic performed the same operation on multiple aircraft there is reason to suspect some learning occurs, and the discrepancies on later operations should be less than previous and may be unrelated to the feedback system. To examine this claim look at **Error! Reference source not found. Error! Reference source not found.** The figure shows the number of discrepancies for a particular operation divided by the average number of discrepancies for all 6 operations on the Y axis, versus the number of times the mechanic has done the same operation on multiple aircraft along the X axis. The number of discrepancies for a particular operation divided by the average number of discrepancies for all 6 operations is used to normalize the data across operations since some operations have more opportunities for discrepancies than others. The data set for this plot is limited to:

- Mechanics that performed the same operation on at least 6 different aircraft

⁸ (Urdan, 2005 pp. 90, 98-99)

- Mechanics with less than 5 years of experience
- Operations with a maximum of 2 mechanics working on them

These limits ensure data points of mechanics with the greatest chance of learning. The data set includes 135 unique mechanics, working on 232 unique operations across 37 different aircraft, and provided 331 unique sets of data (unique mechanic and operation).

To clarify, please remember Bob the mechanic. Bob has installed the main wiring harness six times on six different aircraft and is getting pretty good at it. The first time (repetition #1) the inspector found 18 discrepancies, and on subsequent installations (repetitions #2-5) inspectors found: 15, 7, 9, 9, and 2 discrepancies respectively. This results in an average of 10 discrepancies for all 6 repetitions ($18 + 15 + 7 + 9 + 9 + 2 = 60 / 6 = 10$). If we were to plot Bob's results on Figure 12, the first point would be (1, 1.8): 1 for the first repetition, 1.8 for $18 / 10$. The remaining points would be (2, 1.5) (3, 0.7) (4, 0.9) (5, 0.9) and (6, 0.2).

Figure 13 below shows the histograms for each repetition. The first line represents the average, while the second the 75th percentile. Note how the distributions shift to the left as the repetitions increase (showing a decrease in discrepancies as the same operation is repeated).

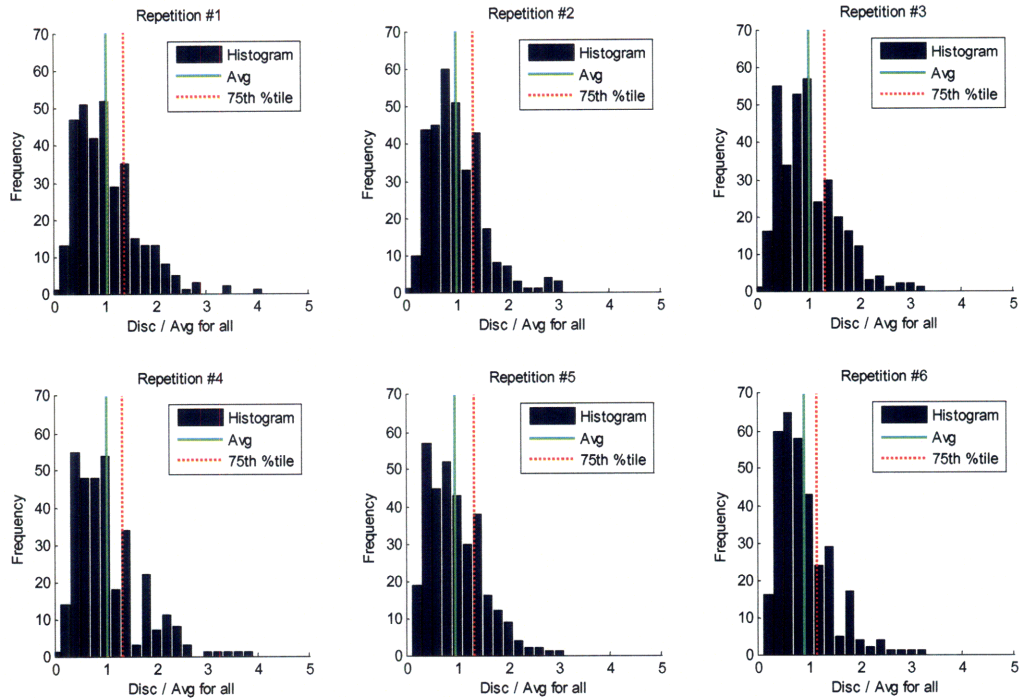


Figure 13: Histograms for learning

There is definitely some learning, but on average over 6 repetitions only 10% of the discrepancies are eliminated, fewer than the 20% shown in the paired data.

AIRCRAFT LEVEL REWORK

One of the more visible and frequently tracked metrics on each aircraft is the total number of discrepancies found on all the operations. This metric is displayed and even has some visibility with USAircraft's customer. Shown below in Figure 14 are the disguised and scaled* discrepancy counts for the aircraft produced before and after the feedback system's introduction. Overlaid on the figure is a line showing the percent of discrepancies from the aircraft that were reworked by the original mechanic.

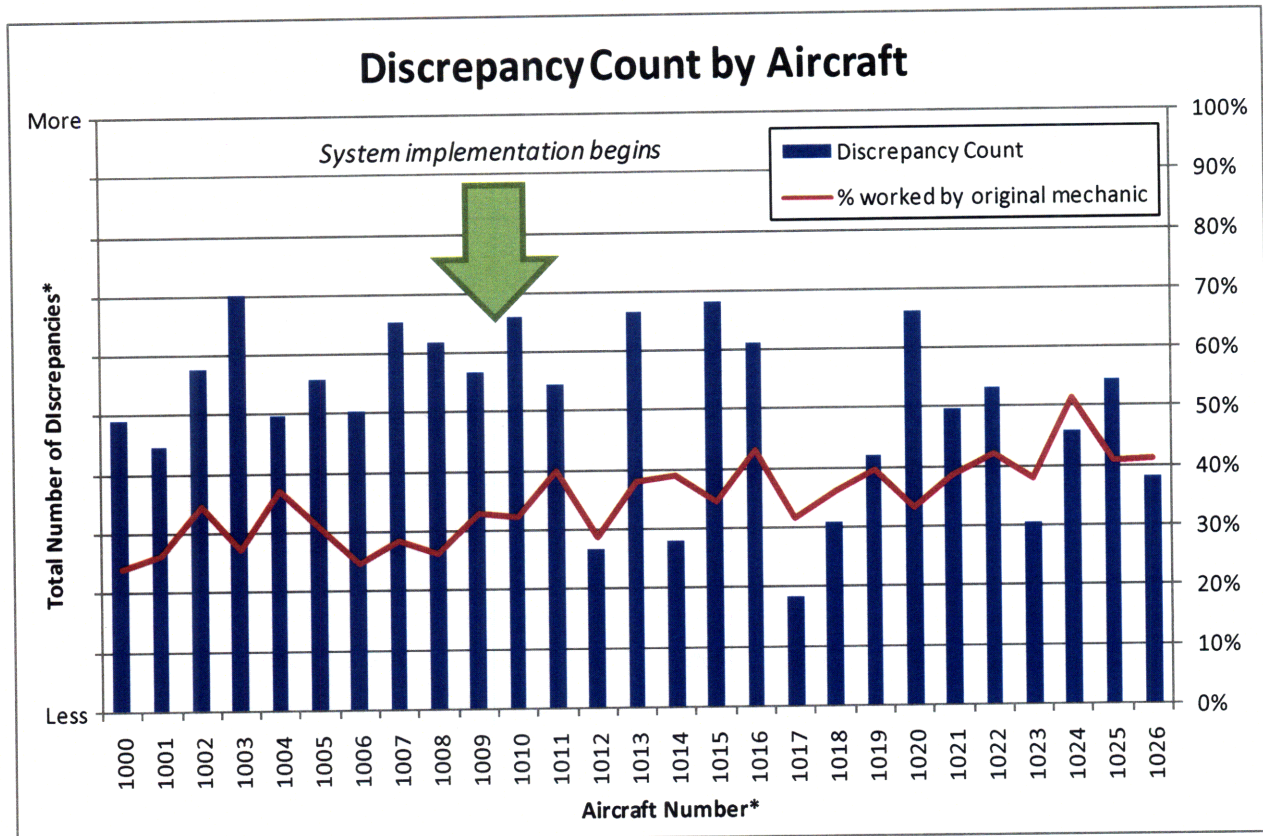


Figure 14: Discrepancy count by aircraft

Aircrafts 1012, 1014, 1017, and 1018 showed great promise in bringing down the amount of rework, but alas the momentum was not maintained and the higher counts returned in an erratic fashion. Plotting the percent of discrepancies worked by the original mechanic on the previous aircraft versus the total number of discrepancies on the current aircraft (see Figure 15 below) seems to suggest a downward sloping relationship as the percent increases, the discrepancy count declines. Using a scaled value of 0 to 1 for the discrepancy counts, and a 0 to 1 for the percent, the slope of the line is -0.58 with a 90% confidence interval of -0.02 to -1.13. Please note this is far from a statistically significant regression; we include it in the thesis merely to suggest there may be some relationship.

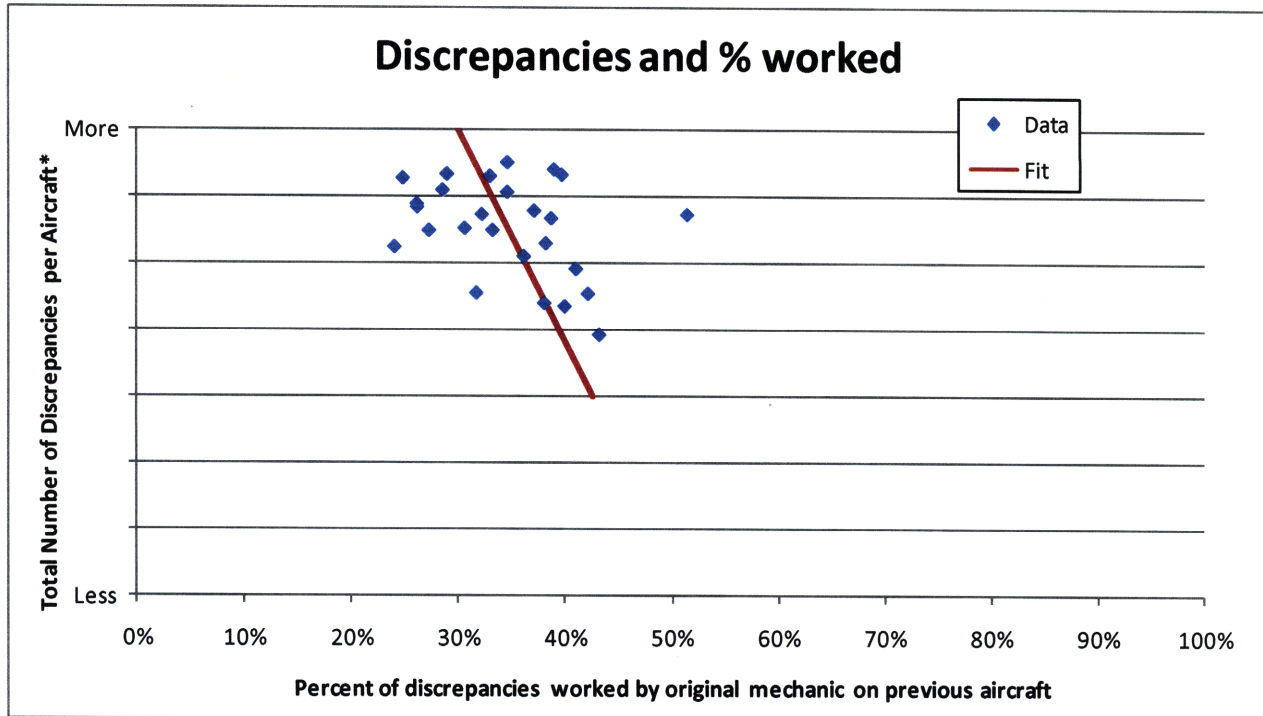


Figure 15: Aircraft discrepancy count versus percent worked

CONCLUSIONS

A close examination of the data shows the feedback system is used (% of discrepancies worked by original mechanics is increasing) and the number of discrepancies by the same mechanic working on the same operation is reduced at a greater rate than that which could be attributed to learning alone. Although there are a few aircraft with dramatically reduced discrepancy counts, later aircraft experienced increases, and the aircraft to aircraft results were not consistent. Although the data and analysis is not available, the author's suspicions and recommendations for further study are to examine the effect of lags in the system and the other factors mentioned in the beginning of this chapter.

Chapter 5 REFLECTIONS ON LEADING CHANGE

Making a meaningful change on the shop floor with an entrenched work force is not easy.

In this chapter are three simple mantras that work well for the author.

“WHAT GETS MEASURED, GETS DONE” - ANONYMOUS

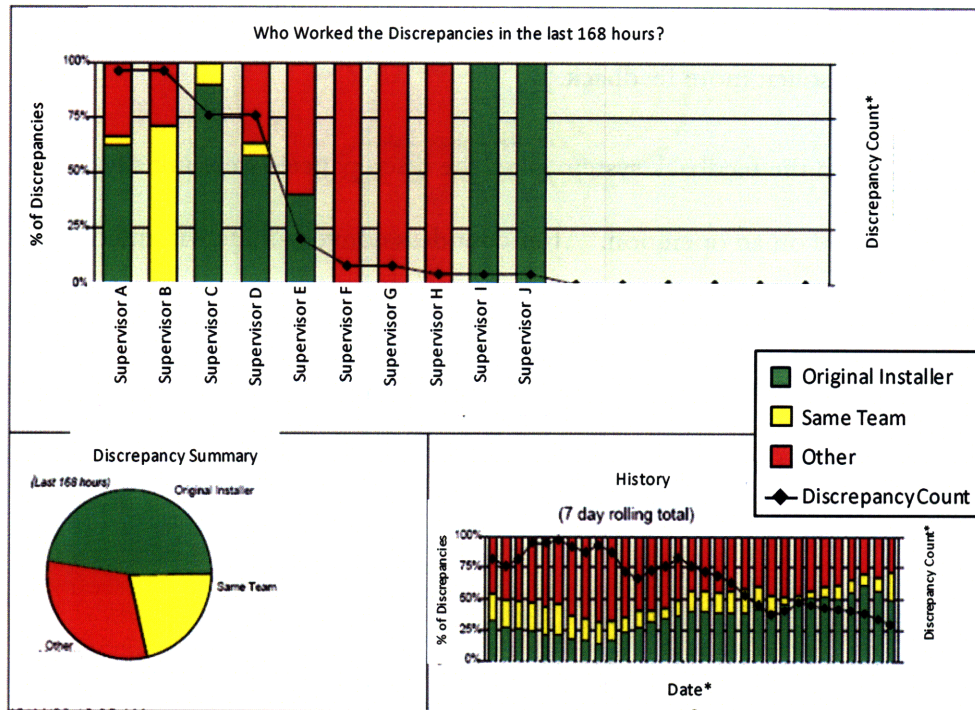


Figure 7: Daily Metrics

Modifying the IT system to print out the discrepancies by installer was the easy part. The real challenge lies in convincing the shop floor personnel to actually use the system. A large leap in adoption was experienced after the metrics shown in Figure 7 above were sent out daily to the operations management team (refer to page 25 for complete explanation of this figure).

RECOMMENDATIONS:

- Ensure the metrics are simple, clear, and easy to read.
- Spend 5-10 minutes with everyone on the distribution list showing them how to read the metrics and what is expected.
- Ensure the team understands where the metrics are coming from and how they can change the ones associated with their name.
- Set up the metrics so they are broken down and it is clear who is accountable.
- Include the historical trend.

FEEDBACK WORKS

No system is perfect the first time it is used, especially on the shop floor. To lead successful change the most important lesson is to walk the shop floor and solicit input on the change and system. Listen attentively, take notes, and reflect on not just what was said, but on the motivations of the stakeholders and what is important to them. Do this continuously, and don't be afraid to make changes often and solicit more feedback.

For example, with the feedback system all of the discrepancies were initially assigned to the last mechanic that worked on an operation. After countless conversations with mechanics complaining they were fixing mistakes made by mechanics on different shifts, the report was changed so all mechanics that worked an operation received the discrepancies. This eliminated the mechanics' concerns and in fact increased visibility of all the mistakes made on an operation to all the mechanics that worked on it.

RECOMMENDATIONS:

- Write down the names of everyone using the system, and make it a point to talk with all of them within a week. Be sure to include all shifts.
- Ask open ended questions: "What do you think?" "How can we make it better?" "What would be more useful?" "Can you show me where it makes your job harder?"
- Be patient and listen. Don't defend, explain where needed.
- Be humble. "I didn't think of that, that's a great idea."
- Say thank you, shake their hand, and incorporate their feedback into the next iteration.

SHOP FLOOR (LIKE EVERYWHERE) IS ABOUT TRUST, AND YOU'VE GOT TO EARN IT

If the change leader and team do not have the trust of the folks on the shop floor, the change is doomed. The shop floor needs to trust that the team is looking out for their best interests, and not just imposing another procedure, set of paperwork, or initiative of the month. One way is to take simple small projects that need to be done to help the folks on the shop floor and follow through on them. This doesn't mean doing them all by yourself. You can figure out who is responsible for them, clearly make them accountable for the task and relentlessly follow up until the

task is taken care of. Each success adds to the team's trust, and folks will slowly give you their time and genuine input. You can still earn some trust even if the task was not completed as long as you gave an honest effort and explained in person why it wasn't accomplished.

RECOMMENDATIONS:

- Honesty above all else. Introduce yourself and tell folks exactly why you are there and stress your goal is to help, but you need their help to succeed.
- Follow through promptly on promises (or in person explain why you can't follow through and what you are going to do to make up for it.)
- Respond as quickly as possible when called for help.
- Spend time on the shop floor, and learn the frustrations of the stakeholder's job. Sympathize, listen, and observe.
- Find lots of simple tasks you can help with (track down a replacement keyboard, help refill water coolers, help clean up, teach someone an Excel trick, find a drawing or schematic, ensure a broken printer is fixed or replaced).

Chapter 6 CASE STUDY: RIGHT SIZING ON-HAND INVENTORY⁹

It was 3am and David was working in USAircraft's final assembly area during the 3rd shift per a recommendation from his mentor. David was on his Leaders for Manufacturing internship, and working to implement a quality feedback system to speed the learning curve and reduce discrepant work on the shop floor. While talking to a few shop floor supervisors, David noticed something peculiar. A few mechanics from the flight test hangar were removing good parts from the newest airframe in final assembly (farthest from complete).

David asked the supervisors why the mechanics were removing the parts.

"Oh, that's just some guys from the hangar 'stealing' parts for use on a completed aircraft in the hangar. Materials can't get those parts easily since they are installed at our subcontractor in Texas, we don't stock any here."

David learned this happens every night on a variety of different parts that were installed by the various USAircraft's subcontractors. The supervisor mentioned the hangar folks are nice enough to let them know, so materials can start the process to replace the parts taken from final assembly.

"With any luck, materials will have a replacement part here by the time that airframe is ready to roll to the hangar. Hopefully, my guys will do a good job installing it, which is tough since we don't normally work on parts installed by our subcontractor," added the final assembly supervisor.

David took a note to follow up on this with the hangar operations manager, as well as the production controller. David recalled something from his inventory lectures about safety stock and thought this was a good chance to apply what he had learned.

⁹ This case is developed solely for the basis of class discussion. The case is not intended to serve as an endorsement, source of primary data, or as an illustration of effective or ineffective management. All data and names are disguised.

USAIRCRAFT BACKGROUND

USAircraft was started early in the 20th century by some of the original inventors of manned flight. USAircraft is based in the United States and builds a variety of aircraft. The largest customer is the United States military, but USAircraft sells to various commercial air carriers, private companies, VIP's, as well as foreign militaries and governments. They have plants throughout the United States, as well as some in Europe and China. USAircraft is renowned for their safety and reliability, as well as an extensive parts and support network for their customers.

USAircraft had originally built the entire aircraft in their first plant, but as orders increased they had slowly outsourced various parts of the airframe and controls to subcontractors throughout the US and the world. USAircraft's labor force in several US plants is unionized, but their subcontractors typically are not.

With the war effort in Iraq and Afghanistan, USAircraft has seen a substantial increase in sales, and has outsourced more sub assembly work and increased the workforce in final assembly to keep up with demand. This case focuses on four model variants of aircraft: W, X, Y, and Z*.

ADDITIONAL INTERVIEWS

The hangar operations manager explained a number of the flight controls are not tested as a system until the aircraft is complete and in the hangar or on the flight line. Once an issue is found, the hangar team is under extreme time pressure to diagnose and repair it over night, so the aircraft can continue ground runs and flight tests the next morning. (For safety reasons, ground runs and test flights are done during the day in good weather.) The hangar operations manager mentioned:

“These aircraft are worth millions and typically we are behind schedule, facing penalties, plus our troops need these aircraft as soon as they can get them. We can't afford to have them sitting around waiting days for a guy in Texas to send us a replacement part, especially when there is one on the next airframe just through the door to final assembly.”

David learned from the production controller that since there is no planned demand in the hangar or final assembly for these parts, USAircraft's MRP system does not hold any inventory in the plant. The controller mentioned that every once in a while when there is a high visibility delay, management approves funds to buy some spare parts, but they quickly disappear and aren't replaced. Plus there is huge pressure to increase inventory turns to meet the business goals set by the corporate office (and tied to management bonuses), so any increase in inventory is highly scrutinized. There would have to be a very good business reason to justify having spare parts in the hangar.

DATA

While in the hangar, David ran into a few engineers that were part of the high failure rate assessment team (HFRAT*). The HFRAT* was tasked with finding the root causes for the failing components and with implementing solutions to prevent failures in the future. They kept great data on which parts were rejected from which aircraft and they were nice enough to share their data with David. Using the data, David was able to extract which parts* and how many* were removed in the hangar over the last 3 months (a sample of parts are included in Exhibit 1*). With the help of the planning group, David was also able to find the description*, cost*, leadtime*, and order quantity* for these parts (Exhibit 2*). After talking with the finance and industrial engineering teams, David put together some basic data needed for the business case to stock spare parts in the hangar.

SUGGESTED ASSIGNMENT

Write a brief email (include up to 5 PowerPoint slides as needed) to the general manager of final assembly explaining the expected annual costs and tradeoffs of "borrowing" parts versus an inventory policy to ensure spare parts are available when they are needed. Include your recommendations on how to meet the need for spare parts in the hangar.

EXHIBIT 1: HANGAR REMOVAL DATA*

Part Number	Number of Removals in last 3 months			
	W	X	Y	Z
10200-20836-047	0	1	0	3
70400-27618-099	1	1	0	2
10100-04329-199	0	2	1	0
60100-21906-155	0	0	0	4
30000-02380-029	1	0	0	2
50700-03521-100	0	0	0	2
80000-10272-040	0	0	0	2
60400-09667-188	0	1	0	0

EXHIBIT 2: PART DATA*

Part Number	Description	Cost	Leadtime	Order Quantity
			(Calendar Days)	(units)
10200-20836-047	PANEL ASSY	\$ 877.12	75	3
70400-27618-099	PEDAL ASSY A	\$ 5,178.08	324	1
10100-04329-199	SERVO #1	\$ 19,874.36	231	1
60100-21906-155	ROD ASSY	\$ 4,328.32	423	1
30000-02380-029	SERVO #2	\$ 12,105.98	299	1
50700-03521-100	COUPLING	\$ 47.89	216	12
80000-10272-040	SERVO #3	\$ 6,874.56	231	1
60400-09667-188	SEAL	\$ 92.56	119	5

EXHIBIT 3: OTHER DATA*

Model Variant	Takt Time* (Mdays)	Production in last 3 months (# of Aircraft)	Next Years Production (# of Aircraft)
W	13	3	18
X	7	3	36
Y	9	6	27
Z	3	15	82

* represents expected Takt Time for the next year, In the last 3 months takt times were lower due to learning curve and model upgrades

Estimated Average add'l labor hours per removal	12
Avg Hangar/Final Assembly Wage (per labor hr)	\$75
Estimated Annual Inventory Carrying Cost	15%

Notes

Mday = manufacturing day = 50 weeks * 5 days per week = 250 days per year
 Inventory Costs for the year = average dollar value of inventory * 15%

BINOMIAL DISTRIBUTION REFRESHER

The binomial distribution provides the discrete probability distribution of obtaining exactly n successes out of N trials. Each trial has the probability p of success and $q = (1-p)$ of failure. An example is a series of N coin flips with probability 0.5 of heads. The binomial distribution provides the probability of n flips coming up heads. The mean of the distribution is Np . The standard deviation of the distribution is $\sqrt{Np(1-p)}$. When Np and $N(1-p)$ are each greater than or equal to 5 the normal distribution can be used to approximate the binomial distribution.¹⁰

Recall from basic statistics, given two independent and normal random variables (A and B) characterized by their respective means (μ_A , μ_B) and standard deviations (σ_A , σ_B), their sum is normally distributed with mean ($\mu_A + \mu_B$) and standard deviation ($\sqrt{\sigma_A^2 + \sigma_B^2}$).

ONE SOLUTION

To address the concerns, the estimated costs of “borrowing” parts in the next year will be calculated. To determine the inventory holding costs, we will consider a continuous review inventory policy and calculate the average inventory level for a number of service levels. The demand for each part will be modeled with a binomial distribution based on the probability of removing a part, and the number of aircraft that will roll through the hangar during the parts leadtime. Finally, we will calculate the total cost to USAircraft for a number of service levels and select the optimum service level.

In summary, the costs of “borrowing” parts from final assembly over the next year is more than six times the inventory holding costs and should be pursued post haste. Over all parts and models the savings is over \$120,000 (more than enough to pay for an LFM intern).

¹⁰ (Yule, 1919 pp. 291-310)

BORROWING COSTS

Included below are calculations to quantify the cost of “borrowing” parts. The calculations do not include allowances for damage done during removal or reinstallation in final assembly, nor are any of the delays associated with these unplanned tasks or reordering of final assembly operations due to missing parts “borrowed” by the hangar.

$$Cost = \left(\frac{\text{Aircraft in next period}}{\text{Aircraft in last 3 months}} \right) \cdot \left(\frac{\text{Removals in last 3 months}}{\text{Aircraft in last 3 months}} \right) \cdot \left(\frac{\text{Hours per removal}}{\text{hour}} \right) \cdot \left(\frac{\$ \text{ per}}{\text{hour}} \right)$$

Part Number	Description	Borrowing Costs				Total
		W	X	Y	Z	
10200-20836-047	PANEL ASSY	\$0	\$10,800	\$0	\$14,760	\$25,560
70400-27618-099	PEDAL ASSY A	\$5,400	\$10,800	\$0	\$9,840	\$26,040
10100-04329-199	SERVO #1	\$0	\$21,600	\$4,050	\$0	\$25,650
60100-21906-155	ROD ASSY	\$0	\$0	\$0	\$19,680	\$19,680
30000-02380-029	SERVO #2	\$5,400	\$0	\$0	\$9,840	\$15,240
50700-03521-100	COUPLING	\$0	\$0	\$0	\$9,840	\$9,840
80000-10272-040	SERVO #3	\$0	\$0	\$0	\$9,840	\$9,840
60400-09667-188	SEAL	\$0	\$10,800	\$0	\$0	\$10,800
Total		\$10,800	\$54,000	\$4,050	\$73,800	\$142,650

Table 1: Borrowing Cost calculations

Example for aircraft model Z, part number 60100-21906-155 (Rod Assy):

$$(82 \text{ aircraft}) \cdot \left(\frac{4 \text{ removals in last 3 months}}{15 \text{ aircraft in last 3 months}} \right) \cdot (12 \text{ hrs/removal}) \cdot (75 \$/\text{hr}) = \$19,680$$

ESTIMATING DEMAND DURING LEADTIME

Using the last 3 months of data, one can approximate the probability a part will fail and model the demand using the binomial distribution. For the number of trials, we use the number of aircraft that pass through the hangar during the leadtime of the part.

$$N_1 = \frac{\left(\frac{\text{Leadtime in cal days}}{\text{Takt time in Mdays}} \right) \cdot \left(\frac{250 \text{ Mdays}}{365 \text{ cal days}} \right)}{\left(\frac{\text{Removals in last 3 months}}{\text{Aircraft in last 3 months}} \right)}, p_1 = \left(\frac{\text{Removals in last 3 months}}{\text{Aircraft in last 3 months}} \right)$$

For the cases where a part is used across multiple model variants with different takt times, we can estimate the aggregate demand for all models and variants by summing the normal approximations of the binomial distribution (See Binomial Distribution Refresher section above).

Part Number	Description	Demand during LT characteristics				Aggregate
		W	X	Y	Z	
10200-20836-047	PANEL ASSY		$\mu=2.33, \sigma=1.25$		$\mu=3.40, \sigma=1.65$	$\mu=5.73, \sigma=2.07$
70400-27618-099	PEDAL ASSY A	$\mu=5.67, \sigma=1.94$	$\mu=10.67, \sigma=2.67$		$\mu=9.87, \sigma=2.92$	$\mu=26.20, \sigma=4.41$
10100-04329-199	SERVO #1		$\mu=15.33, \sigma=2.26$	$\mu=3.00, \sigma=1.58$		$\mu=18.33, \sigma=2.76$
60100-21906-155	ROD ASSY				$N=97, p=0.27$	$N=97, p=0.27$
30000-02380-029	SERVO #2	$\mu=5.33, \sigma=1.89$			$\mu=9.07, \sigma=2.80$	$\mu=14.40, \sigma=3.38$
50700-03521-100	COUPLING				$N=49, p=0.13$	$N=49, p=0.13$
80000-10272-040	SERVO #3				$N=53, p=0.13$	$N=53, p=0.13$
60400-09667-188	SEAL		$N=12, p=0.33$			$N=12, p=0.33$

Note: If N, p shown use binomial distribution; if μ, σ use normal distribution

Table 2: Demand during Leadtime

Example for part number 10100-04329-199 (Servo #1):

- First calculate the number of aircraft of model X and Y that pass through the hangar during the leadtime of the part (231 calendar days)

$$N_X = \frac{(231 \text{ cal days}) \cdot \left(\frac{250 \text{ Mdays}}{365 \text{ cal days}}\right)}{(7 \text{ Mdays})} = 22.60 = \text{round to } 23$$

$$N_Y = \frac{(231 \text{ cal days}) \cdot \left(\frac{250 \text{ Mdays}}{365 \text{ cal days}}\right)}{(9 \text{ Mdays})} = 17.58 = \text{round to } 18$$

- Second calculate the probability a Servo #1 fails on model X and Y

$$p_X = \left(\frac{2 \text{ removals in last 3 months}}{3 \text{ aircraft in last 3 months}}\right), p_Y = \left(\frac{1 \text{ removals in last 3 months}}{6 \text{ aircraft in last 3 months}}\right)$$

- Third, calculate the normal approximation for both models

$$\mu_X = N_X p_X = 23 * \frac{2}{3} = 15.33, \sigma_X = \sqrt{N_X p_X (1 - p_X)} = \sqrt{23 * \frac{2}{3} \left(1 - \frac{2}{3}\right)} = 2.26$$

$$\mu_Y = N_Y p_Y = 18 * \frac{1}{6} = 3, \sigma_Y = \sqrt{N_Y p_Y (1 - p_Y)} = \sqrt{18 * \frac{1}{6} \left(1 - \frac{1}{6}\right)} = 1.58$$

- Finally, calculate the aggregate demand of both models

$$\mu_{\text{Servo \#1}} = \mu_X + \mu_Y = 15.33 + 3 = 18.33$$

$$\sigma_{\text{Servo \#1}} = \sqrt{\sigma_X^2 + \sigma_Y^2} = \sqrt{2.26^2 + 1.58^2} = 2.76$$

INVENTORY POLICY AND COSTS

A continuous review (Q, R) inventory policy with varying service levels (α) will be calculated.

We use the order quantity (Q) given in Exhibit 2. For the parts that span multiple models we

calculate the reorder point (R) using the normal distribution ($R = \mu + Z_\alpha \cdot \sigma$). For the parts only

on a single model, we use the inverse binomial distribution with the calculated N number of trials, p

probability of failure, and α service level¹¹. These will ensure that the probability that demand during the leadtime is greater than the reorder point (R) is $(1 - \alpha)$.¹²

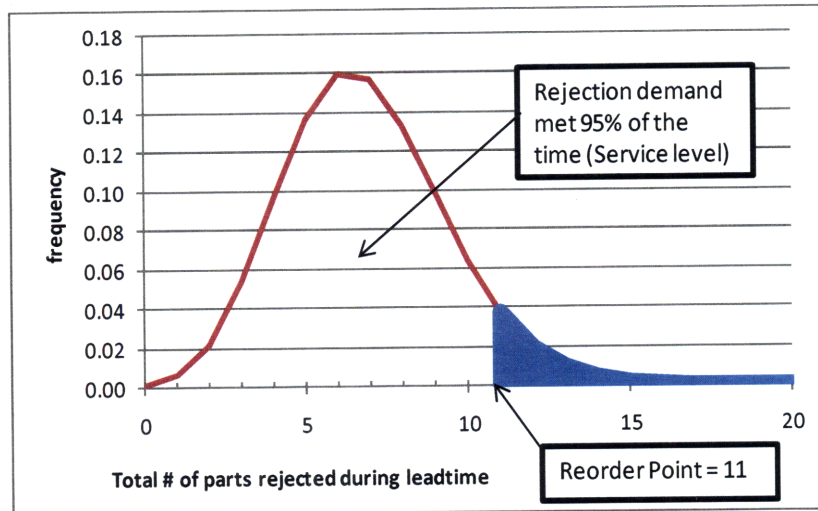


Figure 16: Binomial Distribution

Since $R = \mu + SS$, the Safety Stock level is just $R - \mu$. The average level of inventory is equal to $I = Q/2 + SS = Q/2 + R - \mu$. (Recall for the binomial distribution $\mu = Np$.) The total average inventory cost is simply this average inventory level times the cost per part. The annual inventory holding cost rate is 15%.

To find the optimum service level, we determine the total costs for a range of service levels. The first part of the total cost is simply the cost per removal times the number of removals for that service level. The second part is the inventory holding cost, which can be calculated from above. Simply pick the service level that results in the lowest cost (see Figure 17 below), and calculate the inventory policy using it.

Example for aircraft model Z, part number 60100-21906-155 (Rod Assy):

$$\begin{aligned} \text{Total Costs} &= \text{borrowing costs} + \text{inventory holding costs} \\ \text{Total Costs} &= \text{borrowing cost}_{\text{all removals}} * (1 - \alpha) + \text{Avg Inventory}_{\alpha} * 15\% \end{aligned}$$

¹¹ The spreadsheet function CRITBINOM(trials, probability, service level) can be very helpful

¹² (Simchi-Levi, et al., 2008 pp. 41-45)

$$Total\ Costs = borrowing\ cost_{all\ removals} * (1 - \alpha) + \left(Q/2 + Z_{\alpha} * \sigma \right) * Price * 15\%$$

$$Total\ Costs = \$25,650 * (1 - \alpha) + (1/2 + Z_{\alpha} *) * \$19,874.36 * 15\%$$

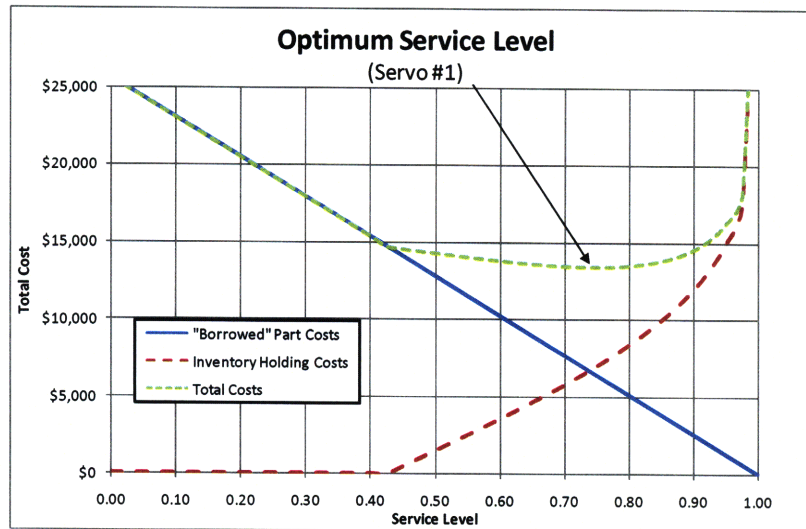


Figure 17: Optimum Service Level

Part Number	Description	Optimum Service Level	Reorder Point	Safety Stock	Avg Inventory Level (units)	Avg Inventory Level (\$)
10200-20836-047	PANEL ASSY	0.98	10	4.27	5.77	\$5,058
70400-27618-099	PEDAL ASSY A	0.90	32	5.80	6.30	\$32,622
10100-04329-199	SERVO #1	0.75	20	1.67	2.17	\$43,061
60100-21906-155	ROD ASSY	0.90	31	5.13	5.63	\$24,383
30000-02380-029	SERVO #2	0.60	15	0.60	1.10	\$13,317
50700-03521-100	COUPLING	1.00	20	13.47	19.47	\$932
80000-10272-040	SERVO #3	0.78	9	1.93	2.43	\$16,728
60400-09667-188	SEAL	1.00	12	8.00	10.50	\$972
Total Avg Inventory Value						\$137,073
Est. Inventory Holding Costs						\$20,561

Table 3: Inventory policy and costs

RECOMMENDATIONS

Since the estimated cost of holding the spare parts inventory (\$20,561) is well below the cost of labor on the redundant removals and re-installations (\$142,650) over the next year, we should stock the spare parts in the hangar per the recommendations. This on-hand inventory also has the added benefits of:

- Improving hangar flow time
- Aiding troubleshooting (easily swap parts)
- Reducing potential for damage in redundant removals and installs
- Reducing paperwork and manpower spent expediting parts

- Reducing rush shipment costs

Of important note is to ensure reorder points are recalculated regularly, due to the fact that the HFRAT team actively reduces the probability of failure of various parts.

Chapter 7 CASE STUDY: EFFECTIVE HANDOFFS¹³

David is a Leaders for Manufacturing intern with USAircraft. David has had a very successful internship with USAircraft. He led a kaizen with a diverse group of operations personnel, and successfully implemented two of the kaizen's recommendations on the final assembly shop floor over the last 5 months. His supervisor, champion, and even the VP of Operations and Quality were impressed with the quality feedback system David and his team implemented on the shop floor (the first recommendation from the kaizen). The second recommendation was to produce a 1 page "Tip of the Day" for all of the mechanics in final assembly on a daily basis. David, with the help of several of the mechanics and shop floor supervisors, had managed to produce and distribute fifty tips so far. The tips were well received (some more than others), and consisted of simple easy to follow advice for the mechanics. They ranged from how to prevent a screw from stripping, to safety tips on how to place the work stands, as well as relevant facts and stories to stress the importance of removing foreign objects from the aircraft (See appendix A1).

With limited time left on his internship, the challenge was to identify, handoff, and train his "Tip of the Day" replacement. David had emailed the final assembly general manager, the operations manager lead, and the lead manufacturing engineer, but had received no reply other than "you're right we do need someone to take it over." David considered the likely candidates:

CONTINUOUS IMPROVEMENT HOURLY TEAM

For each shift and each aircraft model line USAircraft had a few hourly union employees assigned to the continuous improvement team (referred to as guides*). These guides* typically supported a number of improvement projects from 5S initiatives, to documenting recurring issues

¹³ This case is developed solely for the basis of class discussion. The case is not intended to serve as an endorsement, source of primary data, or as an illustration of effective or ineffective management. Some proprietary data and names are disguised and marked with an asterisk (*).

and feeding them back to suppliers, as well as working on standard work documentation. Being in the union and former mechanics working on the line, they knew where the tips were needed, and were very good at taking digital pictures and talking to the right folks about the proper way to perform an operation. Unfortunately, with the increase in production, there were not enough guides* to handle all the recurring issues. Compounding the problem was the concern that producing something that went to everyone was a little risky, if they got something wrong or cast someone's work in the wrong light, they'd hear about this for the rest of their career. On the organization chart the guides* reported to a shop floor supervisor (but there was very little interaction). They received their day to day direction from the continuous improvement coordinators and operation line managers.

CONTINUOUS IMPROVEMENT COORDINATORS

For each model line there was a continuous improvement coordinator. They performed a wide variety of tasks: providing direction to the guides*, tracking metrics, organizing kaizens, applying for improvement certifications, managing six sigma and other lean projects and initiatives. They were all very busy, but were a well connected team. If it happened on the shop floor, odds are the coordinators knew about it. They also had a vast network within the company. This team was very good with PowerPoint, creating web pages, and other computer tasks. They reported to the continuous improvement manager.

CONTINUOUS IMPROVEMENT MANAGER

The continuous improvement manager was new to the company and final assembly. He was eager to gain some respect and trust from the shop floor. He had been in charge of the very successful lean transformation at a sister plant, and was eager to do the same with USAircraft. The continuous improvement team and other operations managers had heard of his success, but were still not quite comfortable with him. He reported into the general manager of final assembly.

MANUFACTURING ENGINEERING ADMINISTRATOR

The manufacturing engineering lead was the guru of lean in final assembly. He was a co-leader of the kaizen that came up with “Tip of the Day”, and strongly believed that the tips would help on the shop floor. He felt so strongly that he freely offered up the time of one of his manufacturing engineering administrators, Sheila*. Sheila was new to final assembly and was eager to take on whatever tasks were assigned, but did not have the strongest computer skills. Sheila was unsure of whom to go to for the right answer, but she did know a few of the mechanics on the floor and was comfortable talking with them.

QUALITY ENGINEERS

The quality engineers were responsible for finding the root cause on any sort of defect found by the inspection team and mitigating the causes in the future. They had their hands full just dealing with the major issues found on the shop floor. Quite frequently the issues could be traced back to lack of mechanic training. Several of the tips dealt specifically with these training gaps. They knew the right way to do a job, and had seen jobs done wrong more than they cared to admit. Every job done incorrectly created more work for the Quality Engineers. They reported through a different chain of command to the VP of Quality (outside the Operations group).

MECHANIC TRAINING SCHOOL INSTRUCTORS

David had approached the training school instructors about a number of the tips of the day. They had been very helpful in finding the correct standard, and had even provided David with lots of good Do’s and Don’ts they had already prepared. With the increase in production, and the abundance of new hires that needed to go through training, the instructors were swamped and understaffed. Although helpful and in full support of the “Tip of the Day”, the instructors were happy to review tips and provide input, but were not willing to assume full responsibility for generating tips on a daily basis.

WHAT TO DO?

David thinks he has a likely team and process in mind for the “Tip of the Day”, but how does he go about empowering them and motivating them to continue the “Tip of the Day”? As an intern he has no real authority, and with the increased production rates, everyone was already busy enough and didn’t have time for more tasks (especially ones the intern used to do).

INTENT OF THE CASE

This case is included to be used in a class discussion to address what the author feels is a recurring theme in many Leaders for Manufacturing internships. The theme is: an excellent cost saving strategic project is often created by the intern and the partner company, but only in rare cases is the project successfully handed off and sustained past the internship. This case is meant to provoke future interns to think about how to hand off their projects and to whom.

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APPENDIX

A1. TIP OF THE DAY EXAMPLES

TIP OF THE DAY

Stripped fastener heads fall into the category of obvious damage, and are frequently written up as an reworkable discrepancies.

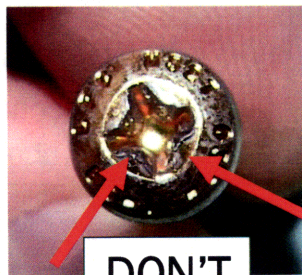
How can I prevent my fastener heads from stripping?

A few common sense tips worth going over with the new folks:

1. Ensure you are working in **good lighting**. Use a drop light, flashlight, even a headlamp.
2. **Check your driver tip**. If it is damaged, worn, stripped this not only introduces FOD, but also increases the odds of a stripped fastener. New driver tips are available at the tool crib.
3. Use the **right tool for the job**. #2 works for the average size screw, use a #1 on a smaller screw. If you are unsure ask your peer, lead, or supervisor for a quick lesson.
4. **Check the length** of the screw before driving.
5. Ensure **driver is square on the screw head**. Driving at an angle is almost guaranteed to strip the fastener head.
6. **Take your time**, and **drive fastener slowly**, this isn't NASCAR, it is more important to do it right the first time, than do it quickly and have to do it again.
7. If possible, use a **hand screw driver** for those last few turns.
8. Once complete, take 5 seconds and **just look at the fastener head**. It is much easier/faster to replace a stripped head now, than pass it down the line to the next installer to fix, or even on to the customer.



DON'T



DON'T

TIP OF THE DAY

Do's & Don'ts

Q: I know I've got my minimum 2 pitches to break safety, but How many threads are too many?

A: As long as:

Fastener size is to the print (or allowable substitute, typically ± 2 sizes)

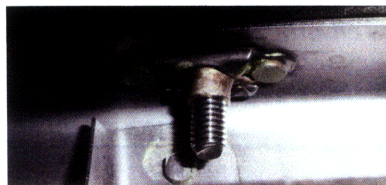
No clearances are violated (doesn't hit anything)

Fastener does not bottom out in the nut

All load/shear is carried by the non-threaded portion

Then your installation is good to go.

*USAircraft quality standard proprietary
information removed*



Maybe
Check for conditions
listed above

